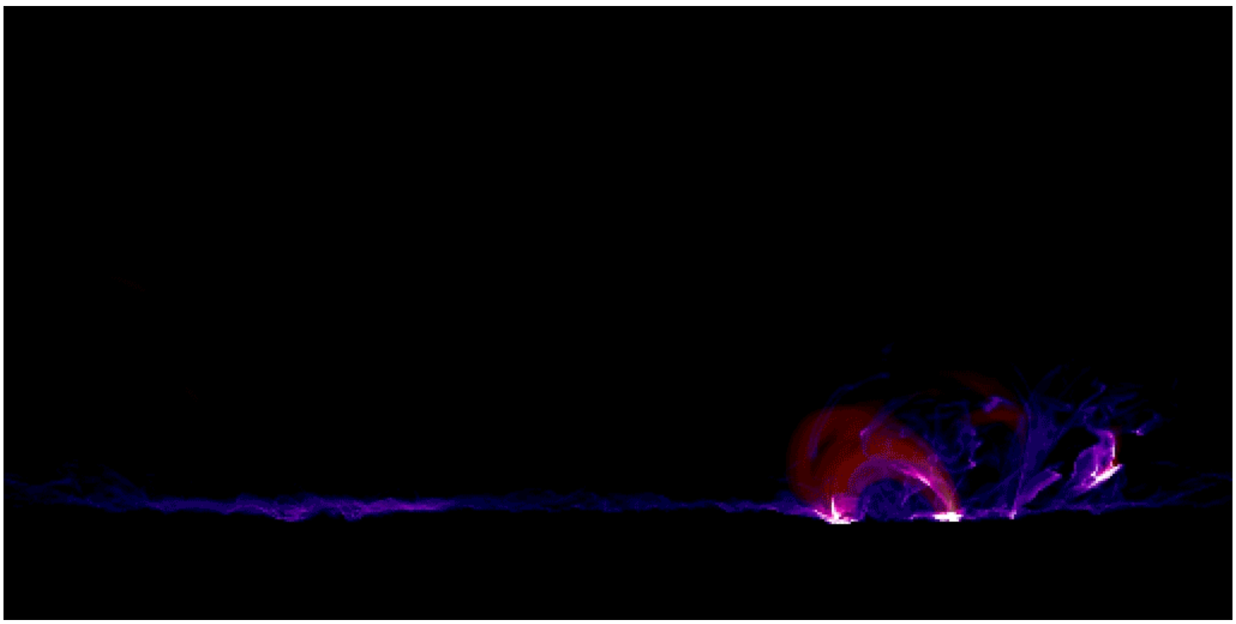
Comprehensive model captures entire life cycle of solar flares

January 15 2019, by Laura Snider



This visualization is an animation of the solar flare modeled in the new study. The violet color represents plasma with temperature less than 1 million Kelvin. Red represents temperatures between 1 million and 10 million Kelvin, and green represents temperatures above 10 million Kelvin. Credit: Mark Cheung, Lockheed Martin, and Matthias Rempel, NCAR

A team of scientists has, for the first time, used a single, cohesive computer model to simulate the entire life cycle of a solar flare: from the buildup of energy thousands of kilometers below the solar surface, to the emergence of tangled magnetic field lines, to the explosive release of energy in a brilliant flash.

The accomplishment, detailed in the journal *Nature Astronomy*, sets the stage for future solar models to realistically simulate the Sun's own weather as it unfolds in real time, including the appearance of roiling sunspots, which sometimes produce flares and coronal mass ejections. These eruptions can have widespread impacts on Earth, from disrupting power grids and communications networks, to damaging satellites and endangering astronauts.

Scientists at the National Center for Atmospheric Research (NCAR) and the Lockheed Martin Solar and Astrophysics Laboratory led the research. The comprehensive new simulation captures the formation of a solar flare in a more realistic way than previous efforts, and it includes the spectrum of light emissions known to be associated with flares.

"This work allows us to provide an explanation for why flares look like the way they do, not just at a single wavelength, but in visible wavelengths, in ultraviolet and extreme ultraviolet wavelengths, and in X-rays," said Mark Cheung, a staff physicist at Lockheed Martin Solar and Astrophysics Laboratory and a visiting scholar at Stanford University. "We are explaining the many colors of solar flares."

The research was funded largely by NASA and by the National Science Foundation, which is NCAR's sponsor.

Bridging the scales

For the new study, the scientists had to build a solar model that could stretch across multiple regions of the Sun, capturing the complex and unique physical behavior of each one.

The resulting model begins in the upper part of the convection zone—about 10,000 kilometers below the Sun's surface—rises through the solar surface, and pushes out 40,000 kilometers into the solar atmosphere, known as the corona. The differences in gas density, pressure, and other characteristics of the Sun represented across the model are vast.

To successfully simulate a solar flare from emergence to energy release, the scientists needed to add detailed equations to the model that could allow each region to contribute to the solar flare evolution in a realistic way. But they also had to be careful not to make the model so complicated that it would no longer be practical to run with available supercomputing resources.

"We have a model that covers a big range of physical conditions, which makes it very challenging," said NCAR scientist Matthias Rempel. "This kind of realism requires innovative solutions."

To address the challenges, Rempel borrowed a mathematical technique historically used by researchers studying the magnetospheres of Earth and other planets. The technique, which allowed the scientists to compress the difference in time scales between the layers without losing accuracy, enabled the research team to create a model that was both realistic and computationally efficient.

The next step was to set up a scenario on the simulated Sun. In previous research using less complex models, scientists have needed to initiate the models nearly at the moment when the flare would erupt to be able to get a flare to form at all.

In the new study, the team wanted to see if their model could generate a flare on its own. They started by setting up a scenario with conditions inspired by a particularly active sunspot observed in March 2014. The actual sunspot spawned dozens of flares during the time it was visible, including one very powerful X-class and three moderately powerful M-class flares. The scientists did not try to mimic the 2014 sunspot accurately; instead they roughly approximated the same solar ingredients that were present at the time—and that were so effective at producing flares.

Then they let the model go, watching to see if it would generate a flare on its own.

"Our model was able to capture the entire process, from the buildup of energy to emergence at the surface to rising into the corona, energizing the corona, and then getting to the point when the energy is released in a solar flare," Rempel said.

Now that the model has shown it is capable of realistically simulating a flare's entire life cycle, the scientists are going to test it with real-world observations of the Sun and see if it can successfully simulate what actually occurs on the solar surface.

"This was a stand-alone simulation that was inspired by observed data," Rempel said. "The next step is to directly input observed data into the model and let it drive what's happening. It's an important way to validate the model, and the model can also help us better understand what it is we're observing on the Sun."

More information: M. C. M. Cheung et al. A comprehensive three-dimensional radiative magnetohydrodynamic simulation of a solar flare, *Nature Astronomy* (2018). DOI: 10.1038/s41550-018-0629-3

Provided by National Center for Atmospheric Research